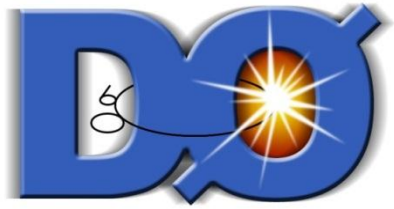
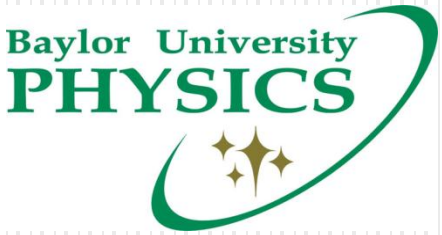


Single Top Production at the Tevatron

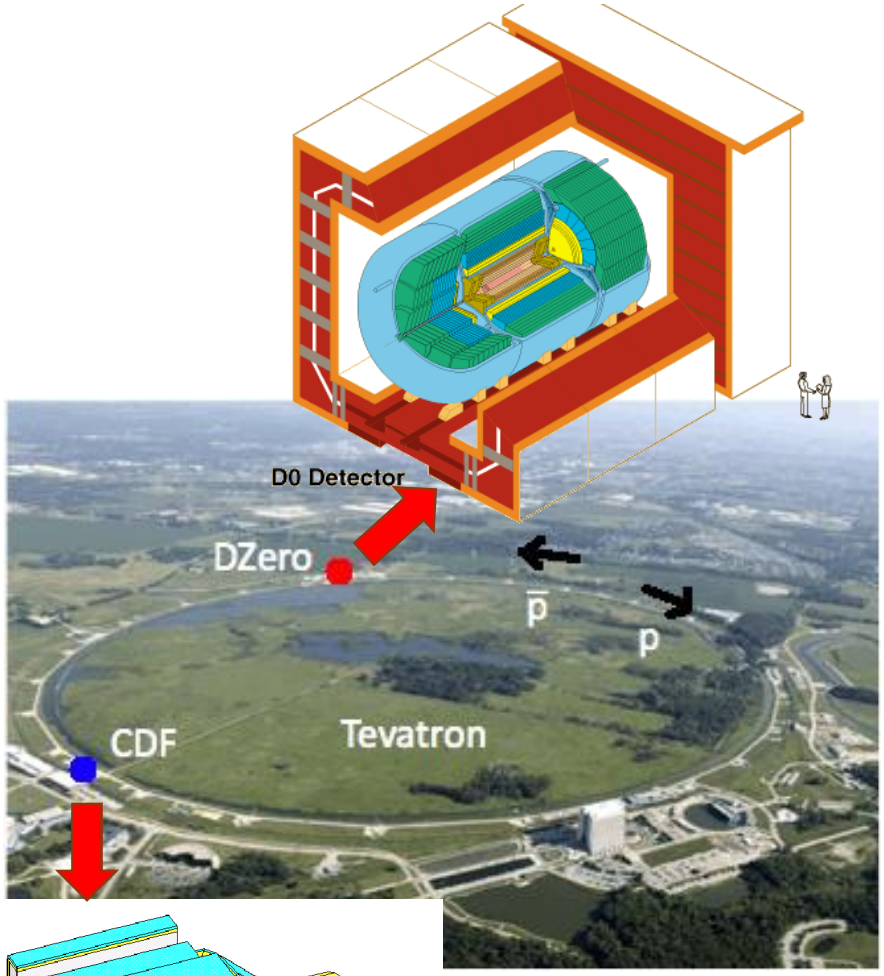
Zhenbin (Ben) Wu
Baylor University
on behalf of the CDF and D0 Collaboration

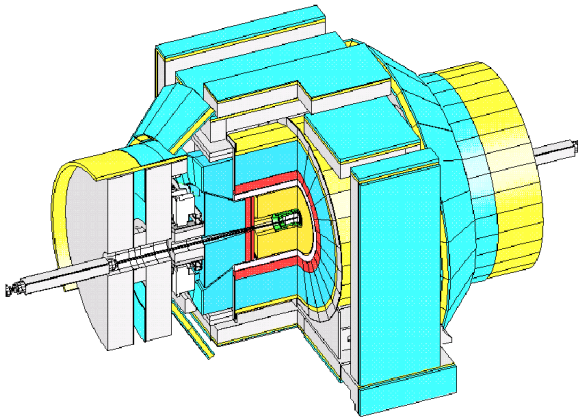
Rencontres de Moriond QCD
March 16, 2012



Outline

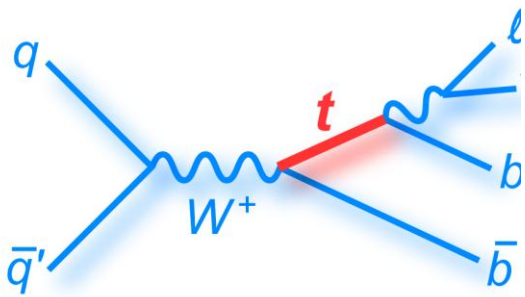
- Introduction
- Lepton+Jets channel
- Single top from D0
- Single top from CDF
- Anomalous Wtb coupling
- Summary



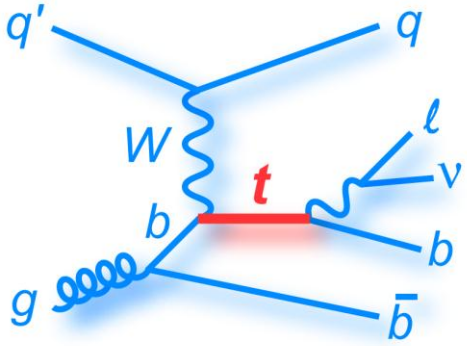


Single top quark

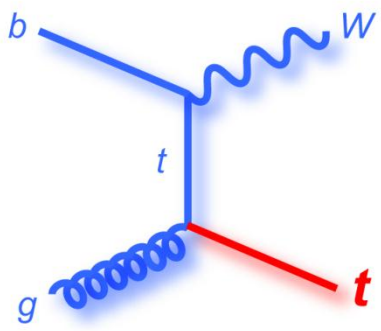
Small at Tevatron



s-channel production



t-channel production

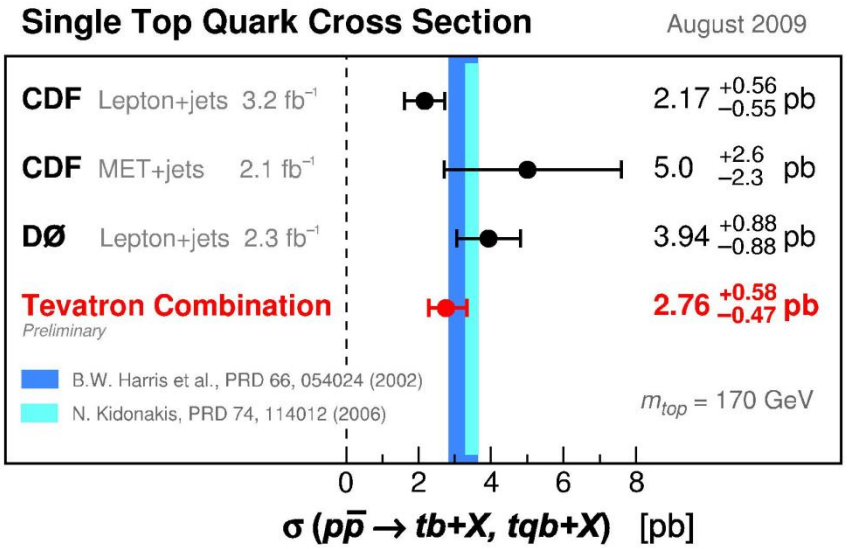


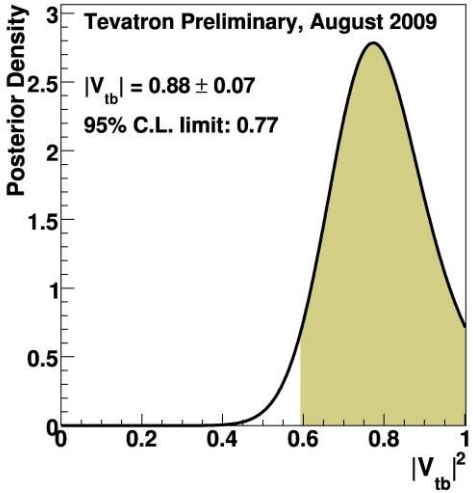
Associated Wt production

- Motivation:
  - Direct measurement of CKM matrix element $|V_{tb}|$ ($\sigma_{s+t} \sim |V_{tb}|^2$)
  - Sensitive to New Physics (FCNC, W'…) and CP violation
  - Additional channel for top quark properties study
- Experimental challenge:
  - Extract small signal out of a large background with large uncertainty

Observation by CDF and D0

- Observed by CDF and D0 simultaneously in 2009
- Over 100 citations for both observation PRLs
  - T. Aaltonen, et al. [CDF collaboration], Phys. Rev. Lett. 103, 092002 (2009)
  - V.M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 103, 092001 (2009)

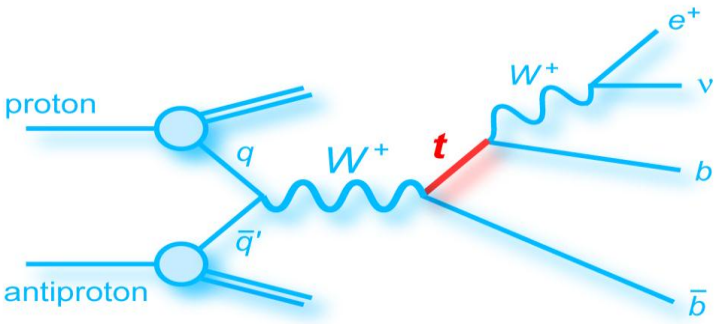




- Combination of CDF and D0:
  - CDF: Four multivariate analysis in Lepton+jets channel with 3.2fb^{-1} data.
  - CDF: MET+Jets channel with 2.1fb^{-1} data
  - D0: Three multivariate analysis in Lepton+jets channel with 2.3fb^{-1} data.

Event signature of Lepton+Jets

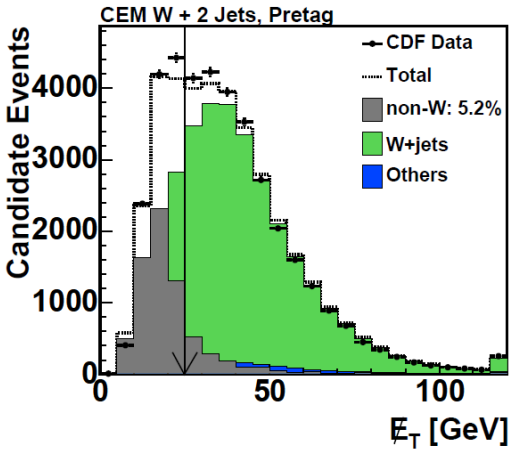
- Main analysis channel: Lepton+Jets
  - Only one isolated lepton
  - Large missing Et from neutrino
  - At least 2 jets
  - At least one of the jets is b-tagged



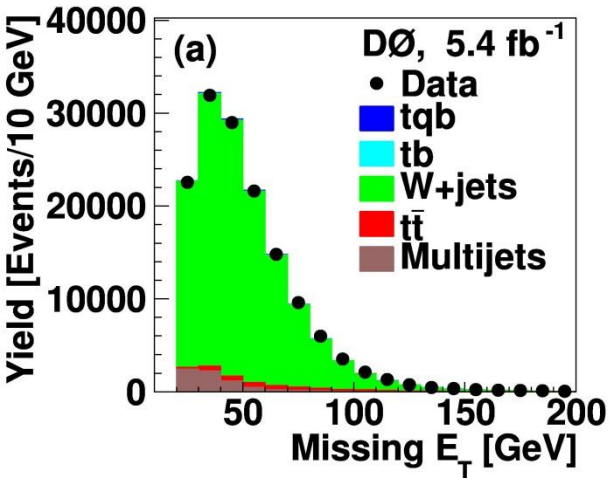
- Background rejection:
  - CDF: Veto QCD, Dilepton, Z and Cosmic
  - D0: Cut on scalar sum (H_T and H_T(alljets)) to suppress QCD and soft-scattering processes
- Still large backgrounds share similar final state after the background rejection.

Background Modeling

- ttbar, diboson and Z+jets are normalized to SM cross section
- QCD models derived from data with non-isolated lepton (D0) or anti-lepton (CDF)
- W+jets are modeled by Alpgen (Wjj, Wbb, Wcc, Wcj)
- W+jets and QCD are normalized to data before b-tagging in missing E_T (CDF) or several variables (D0)



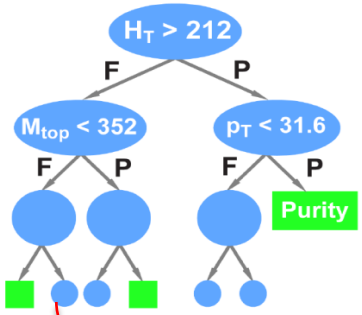
T. Aaltonen, et al. [CDF collaboration], PRD82 112005 (2009)



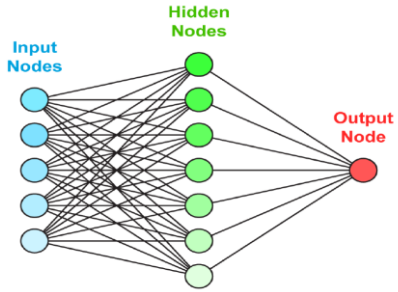
V.M. Abazov et al. [D0 Collaboration], PRD 84, 112001 (2011)

Lepton+Jets analysis with 5.4fb^{-1} data from D0

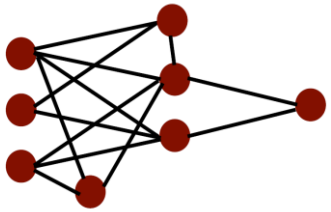
Boosted decision trees



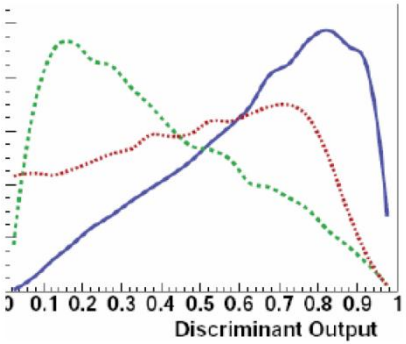
Bayesian neural network



Neuroevolution of augmented topologies

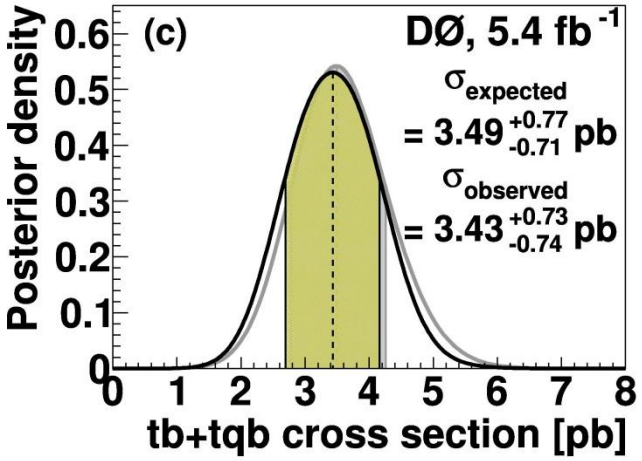


- Signal modeled by SINGLETOP
- Use three multivariate (MVA) methods to extract signal
- Six analysis channels: 2, 3 or 4 jets with 1 or 2 b-tags
- Each MVA method trained separately for s- and t-channel.

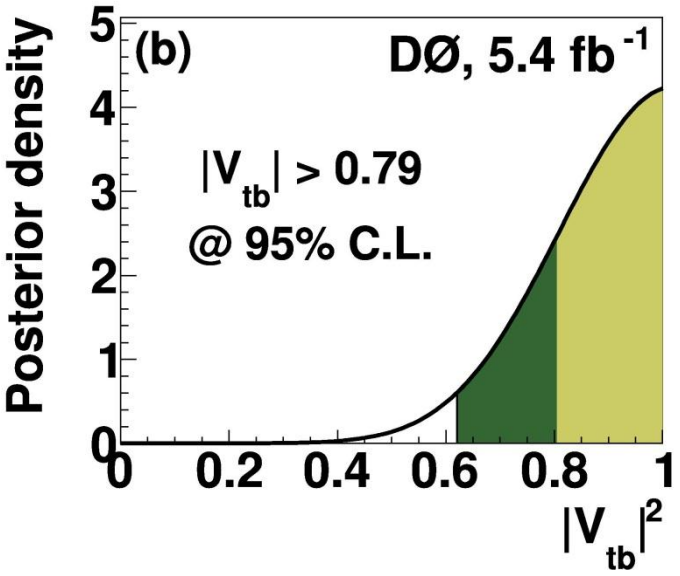


- About 70% correlation
- Combined three MVAs with a final BNN
- Combined s-and t-channel discriminant with SM predicted relative ratio

Cross Section Measurement



- Cross section measured using Bayesian approach
- It is given by the position of the posterior density peak, with 68% interval as uncertainty.

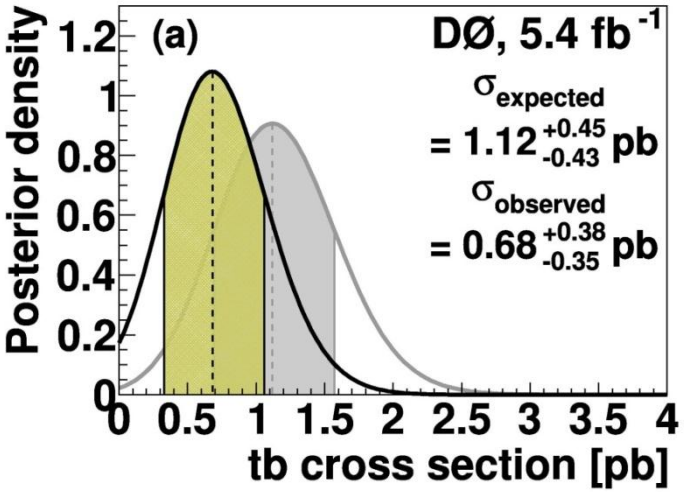


- Since $\sigma_{s+t} \propto |V_{tb}|^2$, directly measure $|V_{tb}|$ from σ_{s+t} posterior with more systematic uncertainties considered
- Assuming
  - $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$
  - Pure V-A and CP conserving Wtb vertex

V.M. Abazov et al. [D0 Collaboration], arXiv:1108.3091

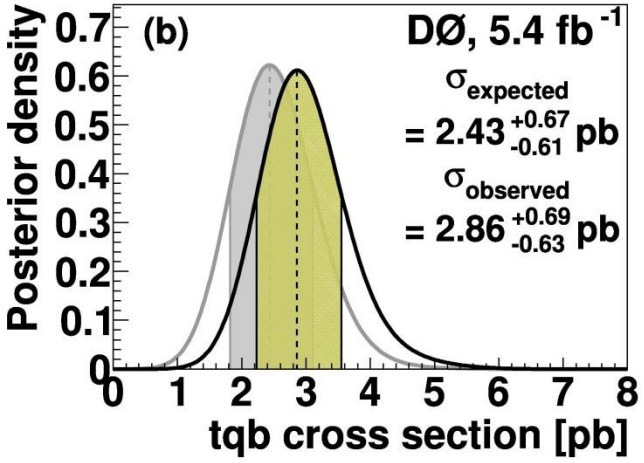
Separate channel measurement

s-channel



- $\sigma_s = 0.68^{+0.38}_{-0.35}$ pb
- No evidence for s-channel yet

t-channel

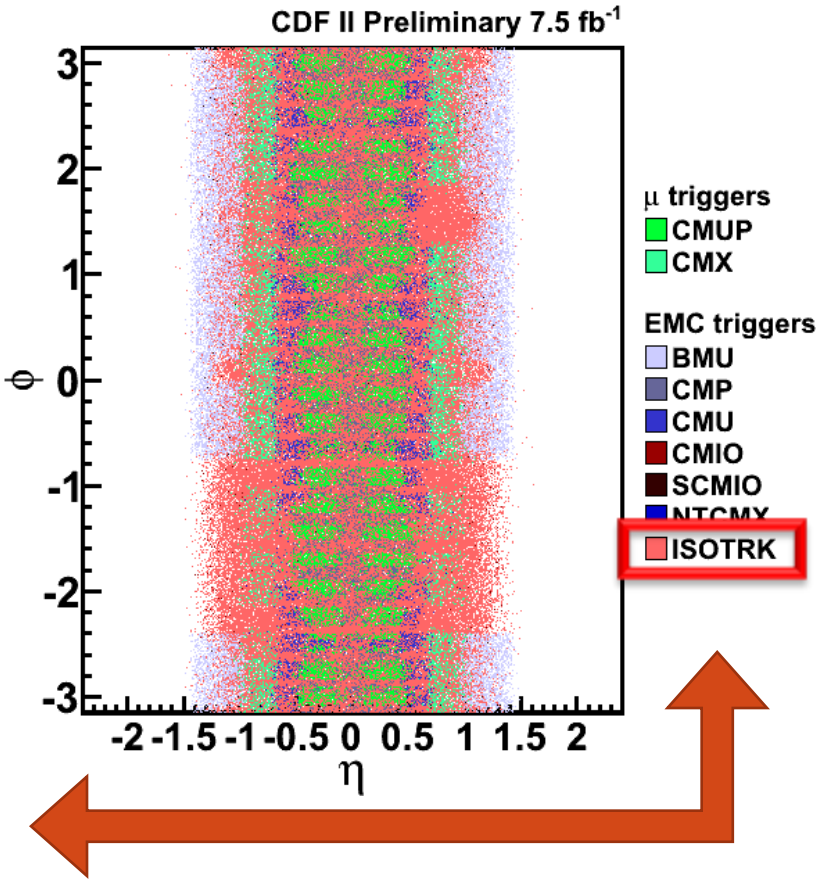


- $\sigma_t = 2.86^{+0.69}_{-0.63}$ pb
- Model independent search
  - 5.5 SD first obsveration!

V.M. Abazov et al. [D0 Collaboration], PRD 84, 112001 (2011)
V.M. Abazov et al. [D0 Collaboration], PLB 705, 313 (2011)

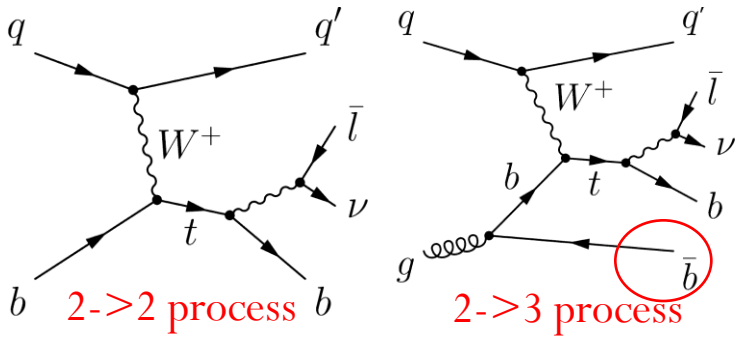
Lepton+Jets analysis with 7.5fb^{-1} data from CDF

- First update since 3.2fb^{-1} analysis from CDF
- Performed in Lepton+Jets events with 7.5fb^{-1} data collected by CDF Run II using Neural Network discriminant
- Add new lepton category: ISOTRK
  - High quality, high P_T isolated track
  - ~15% gain in single top acceptance

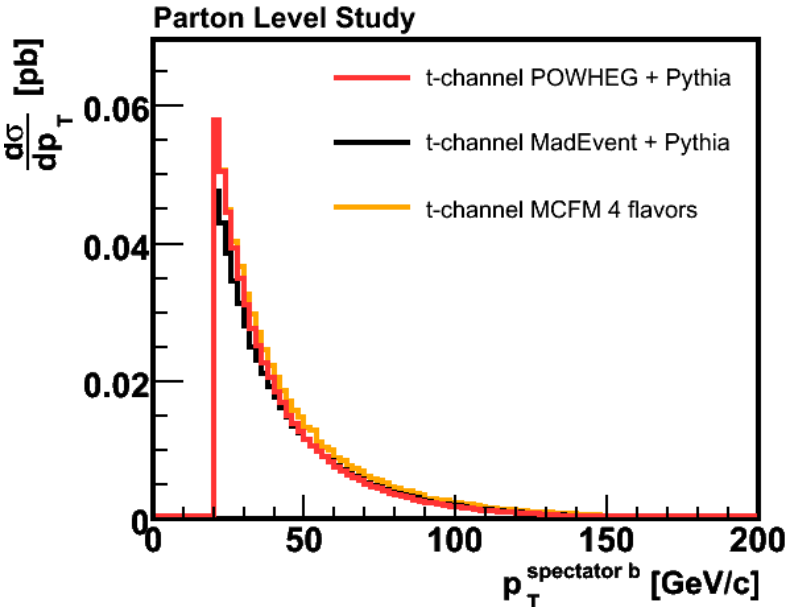


Signal Modeling

- Previously used MadEvent for single top modeling
  - Manually mix two processes of t-channel according to ZTOP prediction
- Using POWHEG for single top modeling with NLO accuracy



t-channel production

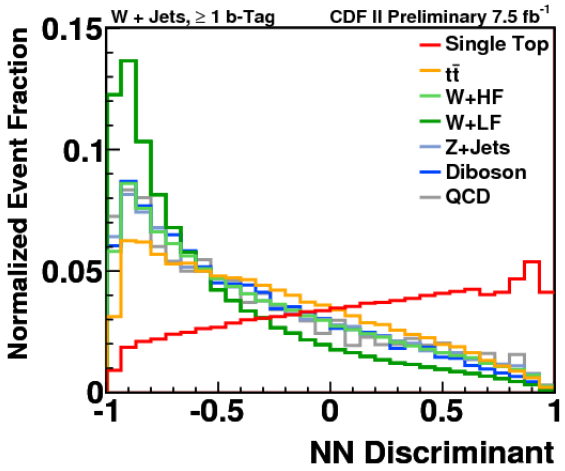


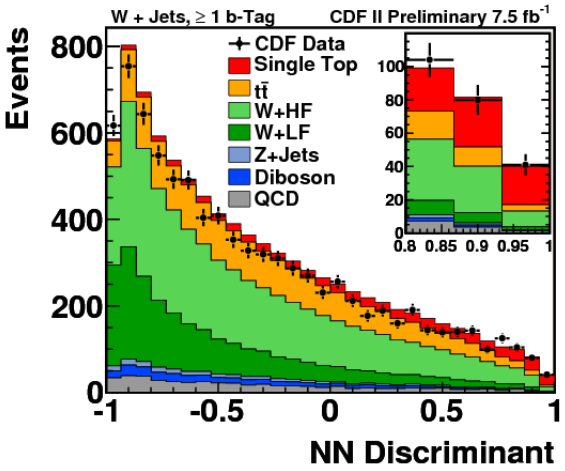
- t-channel shows good agreement with MCFM 4 flavor prediction for both POWHEG and MadEvent
- Add Wt-channel as signal through POWHEG

Zhenbin Wu, Baylor University
arXiv:0907.4076v2; arXiv:1004.1181v4
Phys. Rev. Lett. 102 (2009) 182003

Neural Network

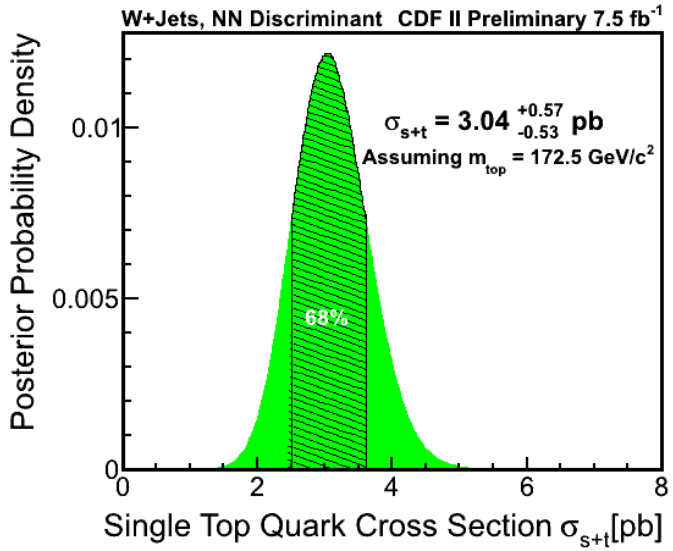
- Train the NN with 11~14 variables in four channels (2, 3 jets with 1, 2 b-tags)
- Train for s-channel in 2 jet 2 b-tags, train for t-channel in the rest channels
- Train the NN with systematic mixed samples for better uncertainty constraint (~3% improvement expected)





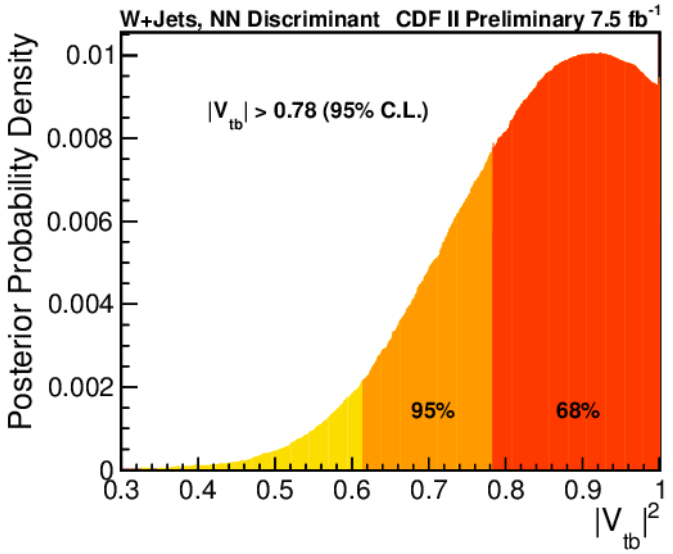
Cross Section and V_{tb}

new



- Assuming $m_{top} = 172.5\ \mathrm{GeV}/c^2$
- Measured cross section:

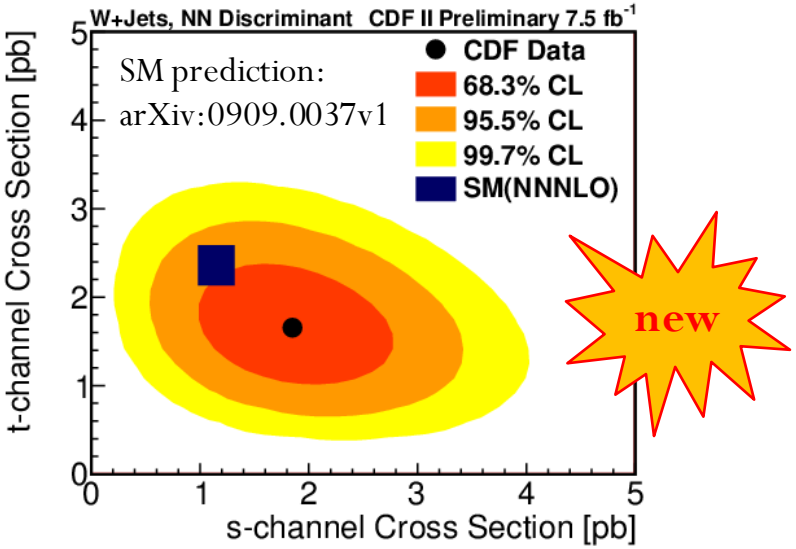
$$\sigma_{s+t} = 3.04^{+0.57}_{-0.53}\ \mathrm{pb}$$

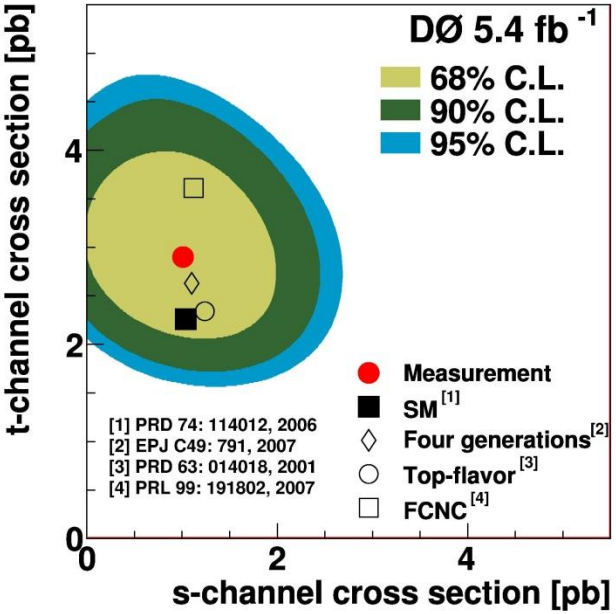


- From the cross section posterior
- Set limit: $|V_{tb}| > 0.78$ at 95% CL

Extracted $|V_{tb}| = 0.92\ ^{+0.10}_{-0.08}\ (\mathrm{stat.+sys.}) \pm 0.05(\mathrm{theory})$

Simultaneous 2D measurement





- Measured cross section:
  - $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb (± ~33%)
  - $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb
- SM Prediction:
  - $\sigma_s^{SM} = 1.05 \pm 0.07$ pb
  - $\sigma_t^{SM} = 2.10 \pm 0.19$ pb
  - $\sigma_{wt}^{SM} = 0.22 \pm 0.08$ pb (Effect negligible)

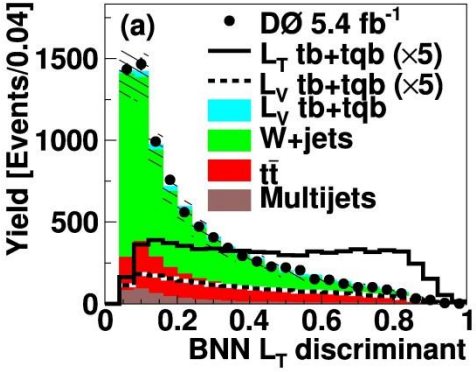
- Measured cross section:
  - $\sigma_s = 0.98 \pm 0.63$ pb
  - $\sigma_t = 2.90 \pm 0.59$ pb (± 20%)
- SM Prediction:
  - $\sigma_s^{SM} = 1.04 \pm 0.04$ pb
  - $\sigma_t^{SM} = 2.26 \pm 0.12$ pb

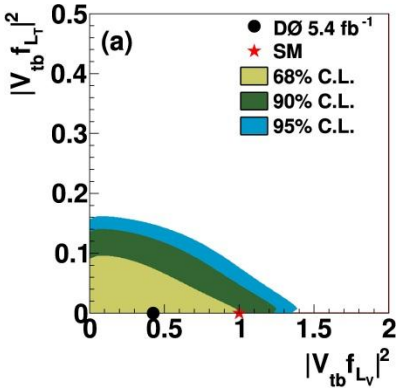
Anomalous Wtb coupling

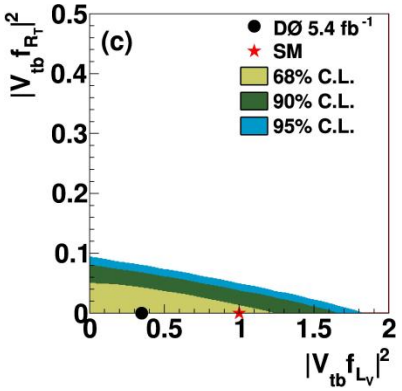
- In the SM, the Wtb vertex is purely left-handed vector coupling
- $\sigma_{s+t} \sim |\text{Wtb coupling}|^2$ assuming single top is produced only via W boson exchange.
- Trained BNN for three coupling scenarios
- Compute 2D posterior probability as a

function of $|V_{tb} \cdot f_{Lv}|^2$ and $|V_{tb} \cdot f_X|^2$ ($f_X = L_T, R_V, R_T$)

- Set upper limit with SM constraint, $|V_{tb} \cdot f_{Lv}|^2 = 1$







Scenario	Cross section	Coupling
(L_V, L_T)	< 1.21 pb	$\lvert V_{tb} \cdot f_{L_T}\rvert^2 < 0.13$
(L_V, R_V)	< 2.81 pb	$\lvert V_{tb} \cdot f_{R_V}\rvert^2 < 0.93$
(L_V, R_T)	< 0.60 pb	$\lvert V_{tb} \cdot f_{R_T}\rvert^2 < 0.06$

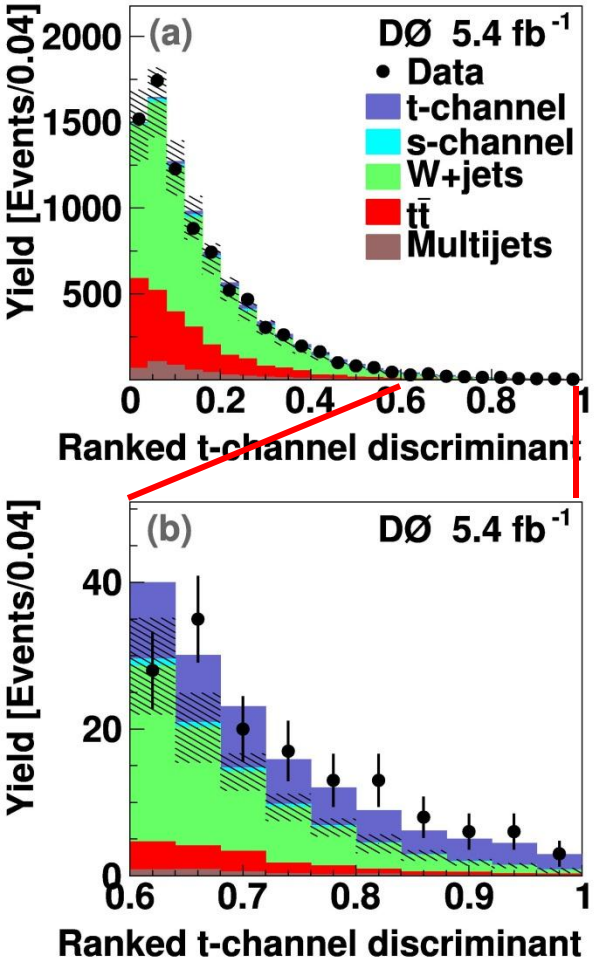
Summary

- We presented the most recent single top analysis and anomalous Wtb coupling search at Tevatron
- We are planning for a new combination of CDF and D0 single top results
- With the observation of t-channel, the search of s-channel is a new challenge and long standing Tevatron legacy.
- It is still a treasury for interesting physics, like CP violation
- Looking forward to single top analysis with full Tevatron dataset

CDF Single Top page:
http://www-cdf.fnal.gov/physics/new/top/public_singletop.html
D0 Single Top page:
http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html#singletop

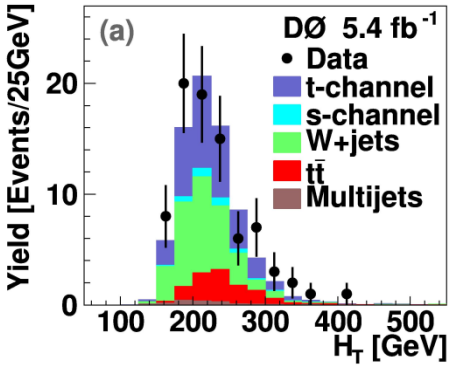
Back up

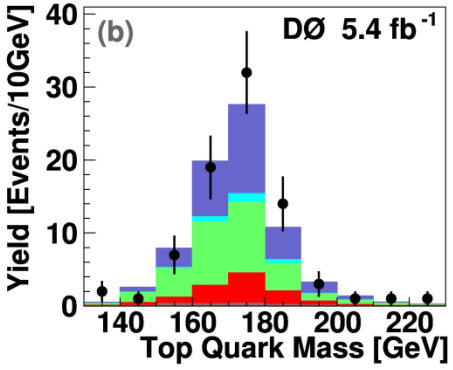
t-channel observation



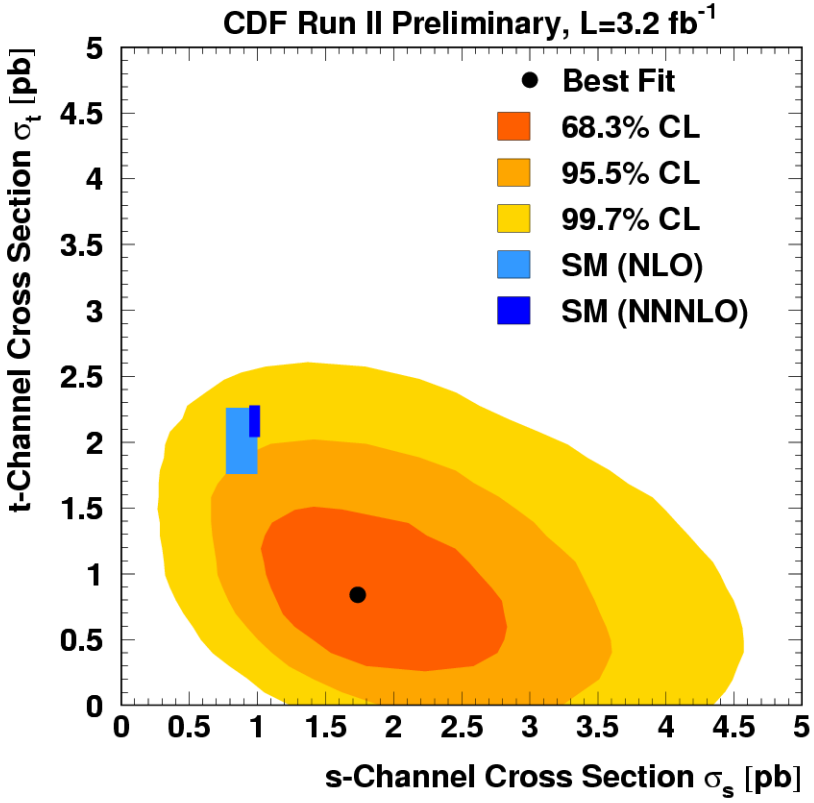
- Expected significance: 4.6 SD
- Measured significance: 5.5 SD

In sample with S:B> 0.32 from final discriminant



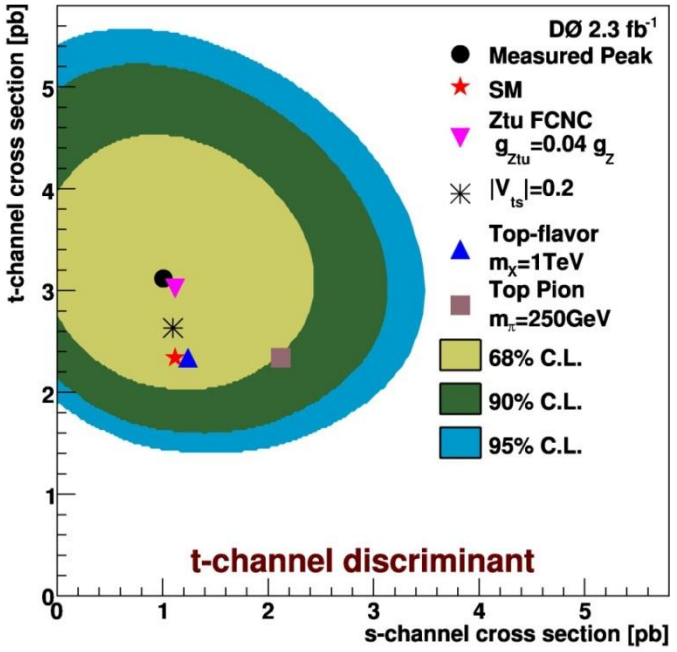


Previous 2D measurements



$$\sigma_s = 1.8^{+0.7}_{-0.5}\ \text{pb}$$

$$\sigma_t = 0.8 \pm 0.4\ \text{pb}$$

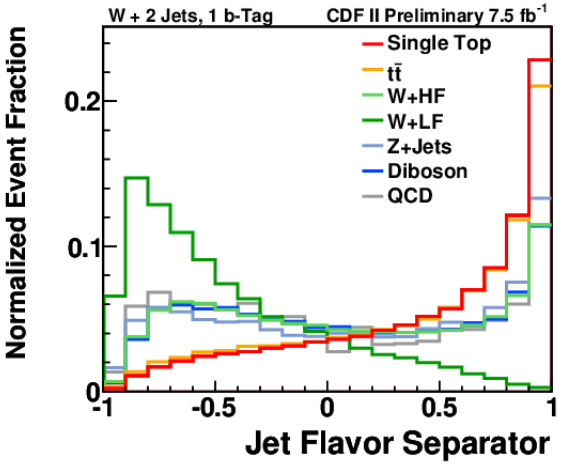


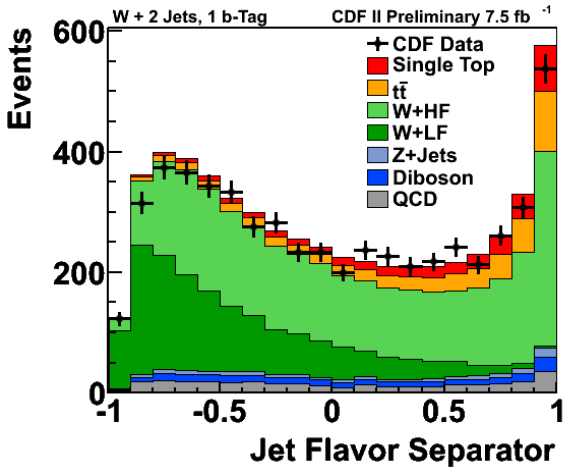
$$\sigma_s = 1.05 \pm 0.81\ \text{pb}$$

$$\sigma_t = 3.14^{+0.94}_{-0.80}\ \text{pb}$$

T. Aaltonen et al. [CDF Collaboration], arXiv:1004.1181v2
V.M. Abazov et al. [D0 Collaboration], PLB 682, 363 (2010)

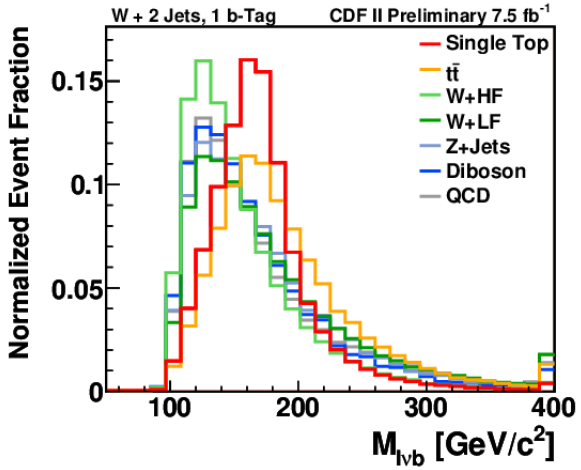
NN input variables

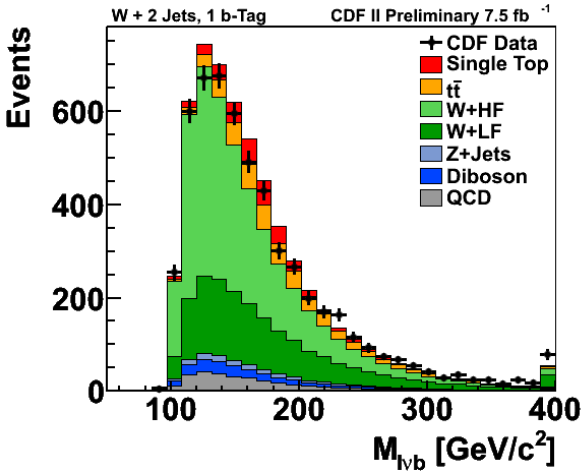


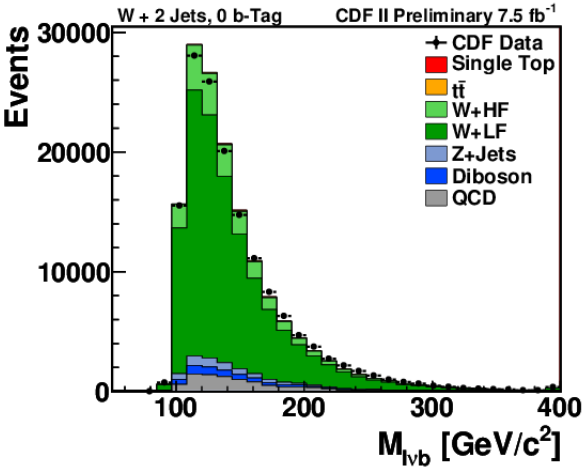


NN jet flavor separator

Reconstructed top mass







Single top

Processes	W + 2 jets, 1 tag	W + 3 jets, 1 tag	W + 2 jets, 2 tag	W + 3 jets, 2 tag
$t\bar{t}$	474 ± 49	1067 ± 109	98 ± 14	284 ± 42
WW	148 ± 21	48 ± 7	1.1 ± 0.3	1.2 ± 0.3
WZ	53 ± 6	14 ± 2	8.8 ± 1.3	2.4 ± 0.4
ZZ	1.7 ± 0.2	0.7 ± 0.1	0.3 ± 0.0	0.1 ± 0.0
Z+Jets	118 ± 15	46 ± 6	4.8 ± 0.7	2.7 ± 0.4
Wbb	1452 ± 437	434 ± 131	183 ± 56	65 ± 20
Wcc	766 ± 233	254 ± 77	10 ± 3	7 ± 2
Wcj	583 ± 177	128 ± 39	7.8 ± 2.4	3.5 ± 1.1
W+Mistags	1459 ± 148	433 ± 47	7.4 ± 1.5	5.4 ± 1.1
Non-W	316 ± 126	141 ± 57	6.8 ± 3.5	3.4 ± 3.2
t-channel	193 ± 25	84 ± 11	6 ± 1	15 ± 2.4
s-channel	128 ± 11	43 ± 4	32 ± 4	12 ± 1.6
Wt-channel	16 ± 4	26 ± 7	0.7 ± 0.2	2.3 ± 0.6
Total Prediction	5707 ± 877	2719 ± 293	367 ± 66	403 ± 53
Observed	5533	2432	335	355

Expected Events

Sources of systematics

Source of Uncertainty	Rate	Shape	Processes affected
Jet energy scale	0–8%	X	all
Initial and final state radiation	0–6%	X	single top, $t\bar{t}$
Parton distribution functions	0–1%	X	single top, $t\bar{t}$
Acceptance and efficiency scale	1–7%		single top, $t\bar{t}$, diboson, Z/γ^*+jets
Luminosity	6%		single top, $t\bar{t}$, diboson, Z/γ^*+jets
Jet flavor separator		X	all
Mistag model		X	W+light
Non-W model		X	Non-W
Factorization and renormalizatio		X	$Wb\bar{b}$
Jet η and ΔR distribution		X	W+light
Non-W normalization	40%		Non-W
$Wb\bar{b}$ and $Wc\bar{c}$ norm	30%		$Wb\bar{b}$, $Wc\bar{c}$
Wc normalization	30%		Wc
Mistag normalization	10–20%		W+light
$t\bar{t}$ normalization	8%		$t\bar{t}$
Monte Carlo generator	3–7%		single top, $t\bar{t}$
Single top normalization	7%		single top
Top mass	2-12%	X	single top, $t\bar{t}$

* X indicates the sources of uncertainty from shape variation
* Sources listed below double line are used only in $|V_{tb}|$ measurement